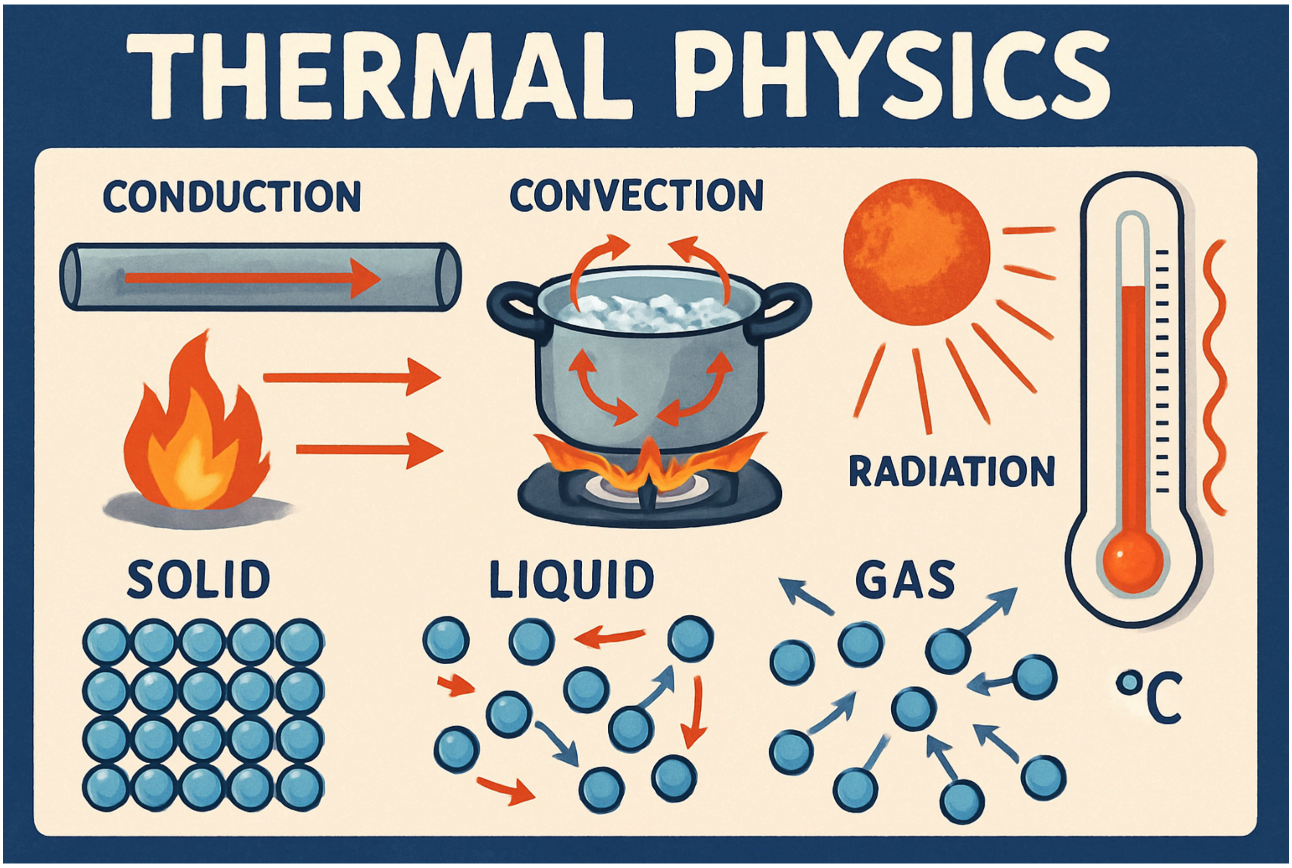
IGCSE Physics: Thermal physics

Syllabus Code: 0625



Learning Objectives

2.1 Kinetic particle model of matter

2.1.1 States of matter

- Know the distinguishing properties of solids, liquids and gases
- Know the terms for the changes in state between solids, liquids and gases (gas to solid and solid to gas transfers are not required)

2.1.2 Particle model

- Describe the particle structure of solids, liquids and gases in terms of the arrangement, separation and motion of the particles and represent these states using simple particle diagrams
- Know that the forces and distances between particles (atoms, molecules, ions and electrons) and the motion of the particles affects the properties of solids, liquids and gases
- Describe the relationship between the motion of particles and temperature, including the idea that there is a lowest possible temperature (−273 °C), known as absolute zero, where the particles have least kinetic energy
- Describe the pressure and the changes in pressure of a gas in terms of the motion of its particles and their collisions with a surface
- Describe the pressure and the changes in pressure of a gas in terms of the forces exerted by particles colliding with surfaces, creating a force per unit area
- Know that the random motion of microscopic particles in a suspension is evidence for the kinetic particle model of matter
- Know that microscopic particles may be moved by collisions with light fast-moving molecules and correctly use the terms atoms or molecules as distinct from microscopic particles
- Describe and explain this motion (sometimes known as Brownian motion) in terms of random collisions between the microscopic particles in a suspension and the particles of the gas or liquid

2.1.3 Gases and the absolute scale of temperature

- Describe qualitatively, in terms of particles, the effect on the pressure of a fixed mass of gas of: (a) a change of temperature at constant volume, (b) a change of volume at constant temperature
- Recall and use the equation pV = constant for a fixed mass of gas at constant temperature, including a graphical representation of this relationship
- Convert temperatures between kelvin and degrees Celsius; recall and use the equation T (in K) = θ (in °C) + 273

2.2 Thermal properties and temperature

2.2.1 Thermal expansion of solids, liquids and gases

- Describe, qualitatively, the thermal expansion of solids, liquids and gases at constant pressure
- Explain, in terms of the motion and arrangement of particles, the relative order of magnitudes of the expansion of solids, liquids and gases as their temperatures rise
- Describe some of the everyday applications and consequences of thermal expansion

2.2.2 Specific heat capacity

- Know that a rise in the temperature of an object increases its internal energy
- Describe an increase in temperature of an object in terms of an increase in the average kinetic energies of all of the particles in the object
- Define specific heat capacity as the energy required per unit mass per unit temperature increase; recall and use the equation $c = \Delta E / (m \Delta \theta)$
- Describe experiments to measure the specific heat capacity of a solid and a liquid

2.2.3 Melting, boiling and evaporation

- Describe melting and boiling in terms of energy input without a change in temperature
- Describe the differences between boiling and evaporation
- Know the melting and boiling temperatures for water at standard atmospheric pressure
- Describe condensation and solidification in terms of particles
- Describe evaporation in terms of the escape of more-energetic particles from the surface of a liquid
- Describe how temperature, surface area and air movement over a surface affect evaporation
- Know that evaporation causes cooling of a liquid
- Explain the cooling of an object in contact with an evaporating liquid

2.3 Transfer of thermal energy

2.3.1 Conduction

- Describe experiments to demonstrate the properties of good thermal conductors and bad thermal conductors (thermal insulators)
- Describe thermal conduction in all solids in terms of atomic or molecular lattice vibrations and also in terms of the movement of free (delocalised) electrons in metallic conductors
- Describe, in terms of particles, why thermal conduction is bad in gases and most liquids
- Know that there are many solids that conduct thermal energy better than thermal insulators but do so less well than good thermal conductors

2.3.2 Convection

- Know that convection is an important method of thermal energy transfer in liquids and gases
- Explain convection in liquids and gases in terms of density changes and describe experiments to illustrate convection

2.3.3 Radiation

- Know that thermal radiation is infrared radiation and that all objects emit this radiation
- Know that thermal energy transfer by thermal radiation does not require a medium
- Know that for an object to be at a constant temperature it needs to transfer energy away from the object at the same rate that it receives energy
- Describe the effect of surface colour (black or white) and texture (dull or shiny) on the emission, absorption and reflection of infrared radiation
- Know what happens to an object if the rate at which it receives energy is less or more than the rate at which it transfers energy away from the object
- Know how the temperature of the Earth is affected by factors controlling the balance between incoming radiation and radiation emitted from the Earth’s surface

- Describe experiments to distinguish between good and bad emitters of infrared radiation
- Describe experiments to distinguish between good and bad absorbers of infrared radiation
- Describe how the rate of emission of radiation depends on the surface temperature and surface area of an object

2.3.4 Consequences of thermal energy transfer

- Explain some of the basic everyday applications and consequences of conduction, convection and radiation, including: (a) heating objects such as kitchen pans, (b) heating a room by convection
- Explain some of the complex applications and consequences of conduction, convection and radiation where more than one type of thermal energy transfer is significant, including: (a) a fire burning wood or coal, (b) a radiator in a car

Core Content

2.1 Kinetic particle model of matter

2.1.1 States of matter

Solids, Liquids, and Gases

Matter exists in three primary states: solid, liquid, and gas. Each state has distinct properties determined by the arrangement, separation, and motion of its constituent particles (atoms, molecules, or ions).

Property	Solids	Liquids	Gases
Arrangement	Regular, closely packed lattice	Random, closely packed	Random, widely spaced
Separation	Very close	Close	Far apart
Motion	Vibrate about fixed positions	Move randomly, slide past each other	Move randomly and rapidly in all directions
Shape	Fixed shape	Takes shape of container	Takes shape of container
Volume	Fixed volume	Fixed volume	Fills entire container
Compressibility	Very difficult	Very difficult	Easy

Changes of State

Changes of state involve the absorption or release of energy without a change in temperature. The terms for these changes are: * **Melting:** Solid to liquid (e.g., ice to water) * **Freezing/Solidification:** Liquid to solid (e.g., water to ice) * **Boiling/Vaporization:** Liquid to gas (e.g., water to steam) * **Condensation:** Gas to liquid (e.g., steam to water droplets) * **Sublimation:** Solid to gas (e.g., dry ice to carbon dioxide gas) and **Deposition:** Gas to solid (e.g., frost formation) are also changes of state, though the syllabus specifies gas to solid and solid to gas transfers are not required for specific terms.

2.1.2 Particle model

Particle Structure and Properties

The properties of solids, liquids, and gases are directly influenced by the forces and distances between their particles, as well as the motion of these particles. For instance, strong intermolecular forces in solids lead to their rigid structure, while weaker forces in liquids allow them to flow. In gases, negligible forces between widely spaced particles result in high compressibility and random motion.

Temperature and Particle Motion

Temperature is a measure of the average kinetic energy of the particles within a substance. As temperature increases, the particles move faster, possessing more kinetic energy. Conversely, as temperature decreases, particle motion slows down. The lowest possible temperature is **absolute zero** (−273 °C or 0 Kelvin), at which particles have the least possible kinetic energy.

Pressure in Gases

Gas pressure arises from the constant, random motion of gas particles colliding with the walls of their container. Each collision exerts a tiny force on the wall. The cumulative effect of these numerous collisions over a given area creates pressure ($p = F/A$). An increase in the frequency or force of these collisions leads to an increase in pressure.

Brownian Motion

Brownian motion is the random, erratic movement of microscopic particles suspended in a fluid (liquid or gas). This phenomenon provides direct evidence for the kinetic particle model of matter. It occurs because the visible microscopic particles are constantly being bombarded by much smaller, invisible, fast-moving atoms or molecules of the fluid. These collisions are random and unbalanced, causing the larger particles to move erratically.

2.1.3 Gases and the absolute scale of temperature

Effect of Temperature and Volume on Gas Pressure

For a fixed mass of gas: * **Change of temperature at constant volume:** If the temperature of a gas increases while its volume is kept constant, the particles gain kinetic energy and move faster. This leads to more frequent and forceful collisions with the container walls, thus increasing the pressure. * **Change of volume at constant temperature:** If the volume of a gas decreases while its temperature is kept constant, the particles have less space to move, leading to more frequent collisions with the container walls. This results in an increase in pressure. This relationship is described by **Boyle's Law**: **Formula:** $pV = constant$ (for a fixed mass of gas at constant temperature)

Temperature Scales

Temperature can be measured using the Celsius (°C) or Kelvin (K) scales. The Kelvin scale is an absolute temperature scale where 0 K represents absolute zero. Conversions between the two scales are straightforward:

Formula: $T(in\ K) = \theta(in\ ^{\circ}C) + 273$

Worked Example: Convert 27 °C to Kelvin. * $T = 27 + 273 = 300K$

2.2 Thermal properties and temperature

2.2.1 Thermal expansion of solids, liquids and gases

Thermal Expansion

Thermal expansion is the tendency of matter to change in volume in response to a change in temperature. When a substance is heated, its particles gain kinetic energy, vibrate more vigorously, and move further apart, leading to an increase in volume. This occurs qualitatively in solids, liquids, and gases at constant pressure.

Relative Magnitudes of Expansion

- **Gases** expand the most for a given temperature rise because their particles are widely spaced and have weak intermolecular forces, allowing them to move much further apart.
- **Liquids** expand more than solids but less than gases. Their particles are closely packed but can slide past each other, allowing for some increase in separation upon heating.
- **Solids** expand the least because their particles are held in fixed positions by strong forces, limiting their ability to move apart.

Everyday Applications and Consequences

Thermal expansion has several practical applications and consequences: * **Bimetallic strips:** Used in thermostats and fire alarms. Two different metals with different expansion rates are bonded together. When heated, they bend due to unequal expansion, activating a switch. * **Gaps in railway tracks and bridges:** Small gaps are left between sections to allow for expansion on hot days, preventing buckling. * **Fitting of metal tyres on wheels:** Metal tyres are heated, causing them to expand. They are then fitted onto wheels and allowed to cool, contracting and forming a tight fit. * **Cracking of glass with hot liquids:** Rapid heating can cause uneven expansion in glass, leading to stress and cracking.

2.2.2 Specific heat capacity

Internal Energy and Temperature

A rise in the temperature of an object increases its **internal energy**. Internal energy is the sum of the random kinetic and potential energies of all the particles within the object. An increase in temperature specifically refers to an increase in the average kinetic energies of these particles.

Specific Heat Capacity (c)

Specific heat capacity is a measure of how much energy is required to raise the temperature of a unit mass of a substance by one degree Celsius (or Kelvin).

Formula: $c = \Delta E/(m\Delta\theta)$ (where ΔE = energy transferred, m = mass, $\Delta\theta$ = change in temperature)

Worked Example: How much energy is required to raise the temperature of 2 kg of water by 10 °C? (Specific heat capacity of water = 4200 J/(kg°C)) * $\Delta E = mc\Delta\theta = 2kg \times 4200J/(kg^\circ C) \times 10^\circ C = 84000J$

Experiments to Measure Specific Heat Capacity

- **For a solid:** A block of the solid is heated using an electric heater. The mass of the block, the power of the heater, the heating time, and the temperature change are measured. Energy supplied ($P \times t$) is equated to energy gained ($mc\Delta\theta$) to find c.
- **For a liquid:** Similar to a solid, but the liquid is typically placed in an insulated calorimeter. The mass of the liquid, power of the heater, heating time, and temperature change are measured to calculate c.

2.2.3 Melting, boiling and evaporation

Phase Changes and Energy Input

- **Melting:** The process where a solid changes to a liquid. Energy is absorbed (latent heat of fusion) to overcome the forces holding particles in fixed positions, without a change in temperature.
- **Boiling:** The process where a liquid changes to a gas throughout the liquid. Energy is absorbed (latent heat of vaporization) to overcome intermolecular forces and push back the surrounding atmosphere, without a change in

temperature. Boiling occurs at a specific boiling point (100 °C for water at standard atmospheric pressure).

Boiling vs. Evaporation

Feature	Boiling	Evaporation
Location	Throughout the liquid	Only at the surface of the liquid
Temperature	Occurs at a specific boiling point	Occurs at any temperature
Bubbles	Formation of bubbles within the liquid	No bubble formation
Speed	Rapid process	Slower process

Condensation and Solidification

- **Condensation:** The process where a gas changes to a liquid. Energy is released as particles lose kinetic energy and come closer together.
- **Solidification (Freezing):** The process where a liquid changes to a solid. Energy is released as particles arrange into a fixed structure.

Evaporation and Cooling

Evaporation is the escape of more-energetic particles from the surface of a liquid. These high-energy particles leave the liquid, reducing the average kinetic energy of the remaining particles. This reduction in average kinetic energy results in a decrease in the liquid's temperature, hence **evaporation causes cooling**.

Factors Affecting Evaporation Rate

- **Temperature:** Higher temperature means more energetic particles, leading to a faster evaporation rate.
- **Surface Area:** Larger surface area allows more particles to escape from the surface, increasing the evaporation rate.
- **Air Movement (Wind):** Wind blows away evaporated particles, reducing the concentration of vapor above the liquid surface and allowing more liquid particles to evaporate.

Explanation of Cooling by Evaporation

When a liquid evaporates from an object (e.g., sweat from skin, alcohol from the skin), the most energetic liquid molecules absorb heat from the object and escape as vapor. This removal of high-energy molecules lowers the average kinetic energy of the remaining molecules on the object's surface, causing the object to cool down.

2.3 Transfer of thermal energy

Thermal energy can be transferred by three main methods: conduction, convection, and radiation.

2.3.1 Conduction

Conduction is the transfer of thermal energy through direct contact, primarily in solids. It involves the vibration of particles and, in metals, the movement of free electrons.

Properties of Conductors and Insulators

- **Good thermal conductors:** Materials that transfer thermal energy efficiently (e.g., metals). Experiments can show that metals heat up quickly when one end is heated.
- **Bad thermal conductors (thermal insulators):** Materials that transfer thermal energy poorly (e.g., wood, plastic, air). Experiments can show that these materials do not transfer heat quickly.

Mechanism of Conduction

- **In all solids:** When one part of a solid is heated, its particles gain kinetic energy and vibrate more vigorously. These vibrations are passed on to adjacent particles through atomic or molecular lattice vibrations, transferring energy through the material.
- **In metallic conductors (additional mechanism):** Metals have **free (delocalised) electrons** that are not bound to any particular atom. When heated, these free electrons gain kinetic energy and move rapidly through the metal, colliding with other electrons and ions, and efficiently transferring thermal energy throughout the material. This is why metals are excellent thermal conductors.

Conduction in Gases and Liquids

Thermal conduction is generally poor in gases and most liquids. This is because: * **Gases:** Particles are far apart and collide less frequently, making energy transfer by collision inefficient. * **Liquids:** Particles are closer than in gases but not in a fixed lattice like solids. Energy transfer by collision is more effective than in gases but less so than in solids, especially metals.

2.3.2 Convection

Convection is the transfer of thermal energy in fluids (liquids and gases) through the movement of the fluid itself. It is an important method of heat transfer in these mediums.

Mechanism of Convection

Convection occurs due to **density changes** in the fluid. When a fluid is heated, it expands, becomes less dense, and rises. Cooler, denser fluid then sinks to take its place, gets heated, and rises. This continuous circulation of fluid creates a **convection current**, transferring thermal energy throughout the fluid.

Experiments to Illustrate Convection

- **In liquids:** Place a crystal of potassium permanganate at the bottom of a beaker of water and gently heat it from below. The purple dye will be seen to rise, spread out, cool, and sink, forming a convection current.
- **In gases:** Place a lit candle under one opening of a convection box (a box with two chimneys). Hold a smoking splint over the other opening. The smoke will be drawn down one chimney, across the box, and up the chimney above the candle, illustrating the convection current.

2.3.3 Radiation

Thermal Radiation is the transfer of thermal energy by **infrared radiation**, which is a type of electromagnetic wave. Unlike conduction and convection, radiation does **not require a medium** for transfer; it can travel through a vacuum.

Emission, Absorption, and Reflection of Infrared Radiation

All objects emit and absorb infrared radiation. The rate at which an object emits, absorbs, or reflects infrared radiation depends on its surface properties:

- **Surface Colour and Texture:**

    - **Dull, black surfaces:** Are good emitters and good absorbers of infrared radiation, but poor reflectors.
    - **Shiny, white surfaces:** Are poor emitters and poor absorbers of infrared radiation, but good reflectors.

Temperature Balance and Earth's Temperature

For an object to maintain a constant temperature, it must transfer energy away at the same rate that it receives energy. If the rate of energy received is greater than the rate of energy transferred away, the object's temperature will rise. Conversely, if the rate of energy received is less, its temperature will fall.

The Earth's temperature is affected by the balance between incoming solar radiation (short-wavelength) and outgoing infrared radiation emitted from the Earth's surface. Factors like atmospheric composition (greenhouse gases) can affect this balance.

Experiments to Distinguish Emitters and Absorbers

- **Emitters:** Fill a Leslie's Cube (a cube with different surface finishes on each side) with hot water. Use an infrared detector to measure the radiation emitted from each surface. The dull black surface will emit the most, and the shiny silver surface the least.
- **Absorbers:** Place identical thermometers with different surface finishes (one dull black, one shiny silver) under a radiant heater. The thermometer with the dull black surface will show a greater temperature rise, indicating it is a better absorber.

Rate of Emission

The rate of emission of radiation depends on the object's surface temperature and surface area. Hotter objects and objects with larger surface areas emit more infrared radiation per unit time.

2.3.4 Consequences of thermal energy transfer

Thermal energy transfer mechanisms (conduction, convection, radiation) have numerous everyday applications and consequences:

Basic Applications: * **(a) Heating objects such as kitchen pans:** Pans are made of metals (good conductors) to efficiently transfer heat from the stove to the food. The handles are often made of insulators (e.g., plastic) to prevent heat transfer to the hand. * **(b) Heating a room by convection:** Heaters warm the air, which rises. Cooler air sinks, creating convection currents that distribute heat throughout the room.

Complex Applications (involving multiple types of transfer): * **(a) A fire burning wood or coal:** Heat is transferred to the surroundings by all three methods: **radiation** (infrared from flames), **convection** (hot air rising), and **conduction** (through the grate or surrounding materials). * **(b) A radiator in a car:** The hot engine coolant transfers heat to the radiator fins by **conduction**. Air flows over the fins, removing heat by **convection**. The hot radiator also emits heat by **radiation**.

Key Terms & Definitions

Term	Definition
Solid	State of matter with fixed shape and volume, particles vibrate about fixed positions.
Liquid	State of matter with fixed volume but takes shape of container, particles slide past each other.
Gas	State of matter with no fixed shape or volume, particles move randomly and rapidly.
Melting	Change of state from solid to liquid.
Boiling	Change of state from liquid to gas throughout the liquid at a specific temperature.
Evaporation	Change of state from liquid to gas only at the surface, occurring at any temperature.
Condensation	Change of state from gas to liquid.
Solidification (Freezing)	Change of state from liquid to solid.
Absolute Zero	The lowest possible temperature (−273 °C or 0 K) where particles have minimum kinetic energy.
Brownian Motion	Random movement of microscopic particles suspended in a fluid, caused by collisions with fluid molecules.
Boyle's Law	For a fixed mass of gas at constant temperature, pressure is inversely proportional to volume (pV = constant).
Thermal Expansion	Tendency of matter to change in volume in response to a change in temperature.
Internal Energy	Sum of random kinetic and potential energies of particles within an object.
Specific Heat Capacity	Energy required to raise the temperature of a unit mass of a substance by one degree Celsius/Kelvin.

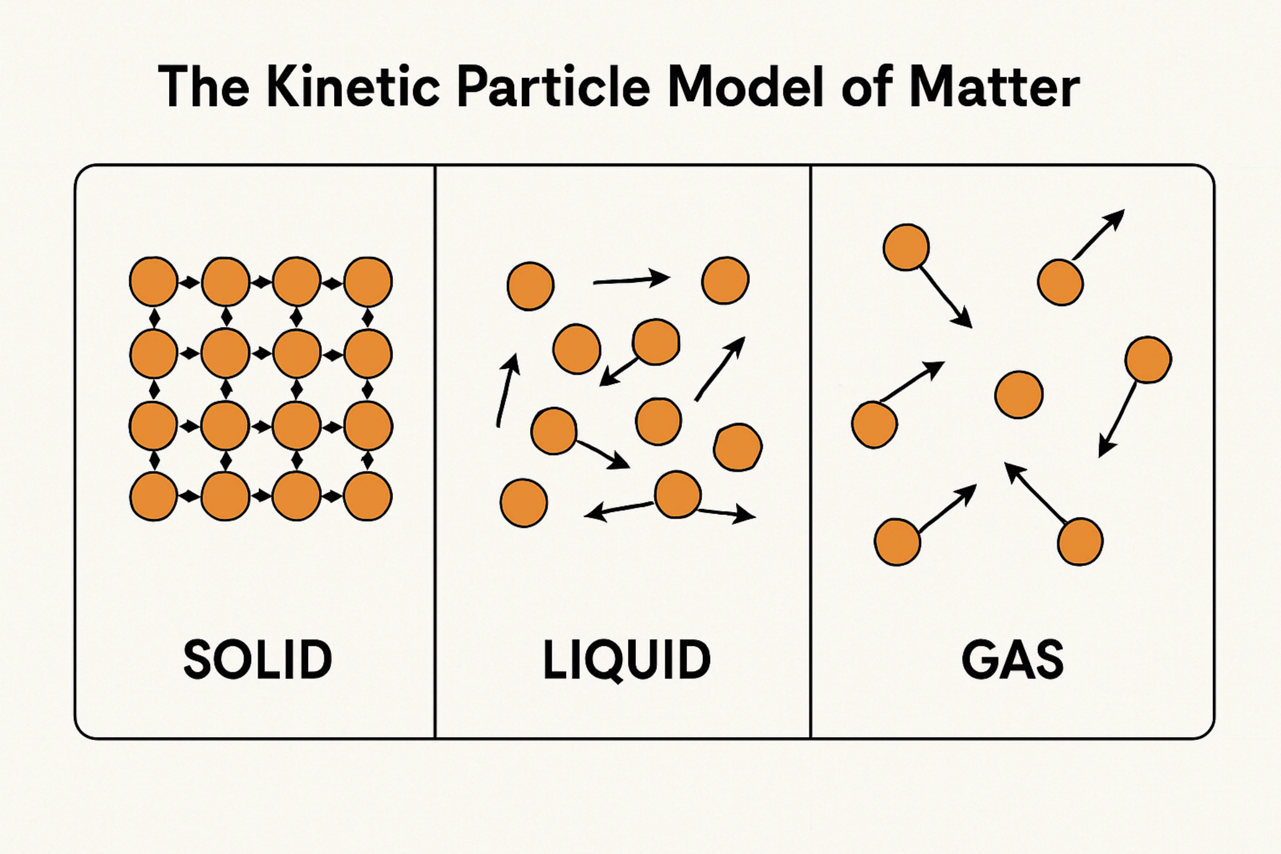
Term	Definition
Conduction	Transfer of thermal energy through direct contact (vibrations and free electrons).
Convection	Transfer of thermal energy in fluids through the movement of the fluid itself (convection currents).
Thermal Radiation	Transfer of thermal energy by infrared electromagnetic waves; does not require a medium.
Good Thermal Conductor	Material that transfers thermal energy efficiently.
Thermal Insulator	Material that transfers thermal energy poorly.
Convection Current	Circulation of fluid due to density changes caused by heating.
Dull Black Surface	Good emitter and absorber of infrared radiation.
Shiny White Surface	Poor emitter and absorber, good reflector of infrared radiation.

Summary & Review

This study guide explored the fundamental concepts of thermal physics. We began with the kinetic particle model of matter, examining the properties of solids, liquids, and gases, and the processes of phase change. We then delved into the relationship between temperature, particle motion, and gas pressure, including Boyle's Law and the absolute temperature scale. The guide also covered thermal expansion, specific heat capacity, and the distinctions between melting, boiling, and evaporation. Finally, we analyzed the three primary methods of thermal energy transfer—conduction, convection, and radiation—along with their mechanisms, properties of materials, and everyday applications.

Further Reading

- Save My Exams: IGCSE Physics - Thermal Physics
- Physics & Maths Tutor: IGCSE Physics Notes
- Khan Academy Physics



- Define specific latent heat as the energy required per unit mass to change the state of a substance at constant temperature; recall and use the equation L = E/m
- Describe experiments to measure the specific latent heat of fusion of ice and the specific latent heat of vaporisation of steam

2.2.3 Melting, boiling and evaporation (continued)

Specific Latent Heat

Specific latent heat (L) is the amount of energy required to change the state of 1 kg of a substance at constant temperature. This energy is used to overcome the intermolecular forces during a phase change, not to increase the kinetic energy of the particles (and thus not to increase temperature).

Formula: $L = E/m$ Where: * L = specific latent heat (J/kg) * E = energy transferred (J) * m = mass of substance (kg)

There are two types of specific latent heat: * **Specific latent heat of fusion (L_f):** The energy required to change 1 kg of a substance from solid to liquid (melting) or liquid to solid (freezing) at its melting point. * **Specific latent heat of vaporisation (L_v):** The energy required to change 1 kg of a substance from liquid to gas (boiling/evaporation) or gas to liquid (condensation) at its boiling point.

Experiments to Measure Specific Latent Heat:

- **Specific Latent Heat of Fusion of Ice:**
    1. Set up a funnel with a heater and a beaker to collect melted ice. Ensure the ice is at 0°C.
    2. Measure the mass of the empty beaker.
    3. Turn on the heater and collect the melted water for a measured time, ensuring all heat supplied by the heater goes to melting the ice.
    4. Measure the mass of the beaker with melted water to find the mass of melted ice (m).
    5. Measure the energy supplied by the heater ($E = P \times t$, where P is power and t is time).
    6. Calculate $L_f = E/m$.
- **Specific Latent Heat of Vaporisation of Steam:**
    1. Set up an electric heater in a flask of boiling water, with a condenser and a beaker to collect condensed steam. Ensure the water is boiling at 100°C.
    2. Measure the mass of the empty beaker.
    3. Turn on the heater and collect the condensed steam for a measured time.
    4. Measure the mass of the beaker with condensed steam to find the mass of condensed steam (m).
    5. Measure the energy supplied by the heater ($E = P \times t$).
    6. Calculate $L_v = E/m$.